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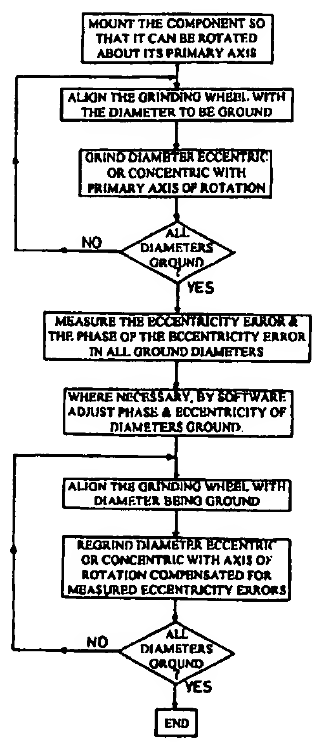
(54) Title: METHODS AND APPARATUS FOR GRINDING CONCENTRIC CYLINDRICAL WORKPIECE REGIONS

(57) Abstract

A method is described for setting up a computer controlled grinding machine for cylindrically grinding concentric workpiece regions, in which a programme containing data about the workpiece and a programme containing wheelfeed instructions are loaded and the wheelfeed instructions programme is run so as to grind at least one such workpiece regions to final form. The region is gauged and the magnitude and angular position of any unwanted eccentricity introduced by the grinding process, is noted, and the whellfeed programme isntructions or control derived therefrom signals are adjusted so that during subsequent grinding of the said region (or a similar region of a similar workpiece), the wheelfeed is controlled so as to compensate for said measured unwanted eccentricity. The workpiece region is stress relieved before the gauging. After setting up, the grinding machine will eccentrically grind a workpiece region which is to have a cylindrical surface concentric relative to the workpiece primary axis, rather than concentrically grinding the said region, the degree of eccentricity being such that when the cylindrically ground workpiece is stress relieved after grinding, the region will be concentric relative to the workpiece axis. A computer controlled grinding machine is described as are programmes for setting up and grinding.



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Title: Methods and Apparatus for grinding concentric cylindrical workpiece regions

Field of invention

This invention concerns the grinding of cylindrical sections of workpieces which should be concentric in rotation, such as the journal bearing regions of a crankshaft.

Background to the invention

During cylindrical grinding, a workpiece is rotated about its primary axis and the or each cylindrical section of the crankshaft is ground in a conventional way by moving a grinding wheel into a grinding position so as to remove material from the workpiece and produce a cylindrical region thereon.

During the grinding operation, unwanted eccentricity may be introduced into such a cylindrical region due to distortion introduced during the grinding step, so-called runout, and as a consequence of stress relieving the workpiece. Any eccentricity introduced into such journal bearing regions of a crankshaft, introduces undesirable wear in the component in use, such as when it rotates in an engine.

It is an object of the present invention provide a method of setting up a grinding machine, and grinding methods, and machines to reduce unwanted eccentricity in supposedly concentric cylindrical regions of ground workpieces.

Summary of the invention

According to the present invention a method of setting up a computer controlled grinding machine for concentrically grinding cylindrical workpiece regions, comprises the steps of

loading a programme containing data about the workpiece, loading a program containing wheelfeed instructions, running the wheelfeed instruction programme so as to grind at least one such workpiece region to final form, measuring any unwanted eccentricity introduced by the grinding process together with the angular position(s) thereof in the said at least one workpiece region, and adjusting the wheelfeed programme instructions or control signals so that during subsequent grinding of the said region (or of similar regions of similar workpieces), the wheelfeed is controlled so as to compensate for said measured unwanted eccentricity.

Preferably the measuring of the workpiece region occurs after it has been stress relieved, which may be achieved merely by disengaging the grinding wheel, but may involve removing the workpiece from the grinding machine.

Application to elongate workpieces

Where a plurality of such regions are to be ground at spaced apart positions axially along an elongate workpiece which is supported at opposite ends, the setting up process measurements may be performed on a concentric cylindrical region approximately midway along the said axial length of the workpiece, and proportionately reduced corrections are applied to the wheelfeed programme instructions or control signals for similar regions to be ground which are displaced from the mid position towards the supported ends of the workpiece.

Alternatively and preferably in a method of setting up a computer controlled grinding machine to machine workpieces in which unwanted eccentricity introduced by the grinding process forces can vary in extent along the axial length thereof (as measured with reference to its supported ends), such that regions towards the centre of the workpiece require a greater degree of eccentricity compensation during grinding as opposed to those adjacent the ends thereof, the method involves the

steps of cylindrically grinding all of the cylindrical surfaces of a workpiece which are to be concentric with the primary workpiece axis without introducing any compensation for unwanted eccentricity introduced by the grinding process forces, thereafter making measurements on the workpiece to determine any unwanted eccentricity and the angular position thereof about the primary workpiece axis of rotation for each of the ground regions, and separately adjusting each of the wheelfeed programme instructions or control signals to be used to control the wheelfeed during the subsequent grinding of the or another such workpiece, at each of the corresponding said regions thereof, so as to compensate individually for any process-induced eccentricity in each said region.

Checking on the corrections

After a setting up process has been performed and the original workpiece has been reground using the corrected wheelfeed programme instructions or control signals, a further check on the reground workpiece may be made, and second order corrections may be made to the wheelfeed programme instructions or control signals, before grinding further workpieces.

Measurements may be made subsequent to each further workpiece grinding to determine whether the corrections made from earlier measurements sufficiently compensate for any unwanted process induced eccentricity, and further corrections may be made to the wheelfeed programme instructions or control signals as required. The process may be repeated until the measurements made on a test workpiece indicate that the unwanted eccentricity of each ground region is within desired limits. Thereafter the grinding machine wheelfeed may be controlled to grind further workpieces in accordance with the finally modified set of wheelfeed programme instructions or control signals.

Multiple workpiece measuring for setting up

Instead of producing only one workpiece on which measurements are made during setting up, it may be preferable at each stage to grind a number of workpieces which together form a sample, and to perform eccentricity measurements on the workpieces in each sample, and thereby determine the extent of any unwanted eccentricity both in terms of angular position and radial extent for each region of each workpiece in each sample, and to determine the mean unwanted eccentricity and mean angular position of such eccentricity for each sample, for use as the basis for the correction to the wheelfeed programme instructions or control signals.

Where samples containing two or more workpieces are used to determine the corrections to be made, the process for determining what is to be the final set of programme instructions or control signals for the wheelfeed, can be terminated either if all of the measurements of unwanted eccentricity in all of the workpieces in a sample fall within desired limits, or if the mean of all the measurements of unwanted eccentricity fall within desired limits. The particular criterion used may depend upon the specification for the component concerned.

The invention also lies in a method of grinding concentric cylindrical regions of similar workpieces comprising the steps of setting up modified wheelfeed programme instructions or control signals in any of the aforesaid ways, and thereafter grinding cylindrical surfaces of workpieces similar to that used in the setting up process, using the modified wheelfeed programme instructions or control signals derived from the setting up procedure, to control the wheelfeed drive.

By using a high speed CBN grinding wheel, it is possible to eliminate the rough machining step typically required before a fine grinding step to produce a bearing surface, thereby allowing a two stage grinding and polishing process to produce a finished product, instead of a three stage process.

The invention thus allows the known software controlled crankpin following facility incorporated into computer controlled grinding machines to permit a grinding wheel to follow the relatively excessive eccentric movement of a crankpin during grinding as the crankshaft rotates, to be utilised, albeit acting at a smaller scale, to compensate for unwanted eccentricity introduced into cylindrically ground surfaces of a workpiece which should be concentric as a consequence of grinding process forces exerted as such surfaces are ground, which unwanted eccentricity tends to appear after the workpiece is stress relieved.

The invention thus in effect provides for eccentrically grinding regions of workpieces which are to have concentric cylindrical surfaces relative to the workpiece primary axis rather than concentrically grinding such regions, the degree of eccentricity being such that when a ground workpiece is stress relieved after grinding, the regions in fact will be concentric relative to the primary axis of the workpiece.

The invention is of particular application to the grinding of journal bearing regions on crankshafts, but it is to be understood that the invention is equally applicable to the grinding of any cylindrical concentric workpiece section so as to remove eccentricity which the grinding process can introduce into the workpiece, and which becomes evident as the latter becomes unstressed.

Apparatus embodying the invention

A computer controlled grinding machine for performing methods of grinding as aforesaid comprises, a grinding wheel, drive means for rotating the wheel, wheelfeed drive means for advancing and withdrawing the grinding wheel towards and away from a workpiece region in a precise manner, computer means for controlling the wheelfeed drive means, which computer means includes memory means for storing programmable wheelfeed

instructions whereby the position of the wheel at each instant during a grinding process can be controlled, programme means loaded into the computer to control advance and withdrawal and position of the grinding wheel, and memory means for storing correction signals for adjusting the original wheelfeed instructions or control signals during the grinding of said regions, or storing corrected wheelfeed programme instructions which correction signals or corrected instructions are obtained from a setting up process as described above. In this way the grinding process performed by the machine will reduce any unwanted eccentricity introduced by grinding process forces into what should be a concentric workpiece region, by grinding each such region so as to be complementarily eccentric to any eccentricity which would be introduced by the grinding process forces. By complementary is meant equal in magnitude but opposite in sense (direction).

Where the grinding wheel is to be moved axially relative to the workpiece (or the workpiece is to be moved axially relative to grinding wheel) to allow different regions to be ground, the computer means includes additional programme instructions to control the movement of the wheel or the workpiece to effect said relative positioning between grinding.

Conveniently the wheelfeed drive includes two modes, a first mode for normal advance and withdrawal, and a second mode in which very small but very precise adjustments can be made to the instantaneous wheel position so that during grinding, with the grinding wheel in contact with the workpiece and surface grinding being performed, the grinding wheel can be urged backwards and forwards by very small amounts in synchronism and appropriate phase with the rotation of the workpiece, using corrected wheelfeed programme instructions or control signals as aforesaid, so as to compensate for any eccentricity which would otherwise arise in the grinding of the workpiece region due to forces arising during the grinding process.

Product produced by the process

The invention also lies in workpieces when made in accordance with any of the aforesaid methods or using the aforesaid grinding machine.

The invention will now be described by way of example with reference to the accompanying drawings, in which:

Figure 1 illustrates a computer controlled grinding machine, fitted with an in process gauge;

Figure 2 is a side view of the gauge to an enlarged scale;

Figure 3 is a diagrammatic illustration of how a gauge is controlled and in turn controls the grinding cycle, via the machine controlling computer; and

Figures 4 is an example of the grinding process steps of one method according to the invention.

Detailed description of the drawings

Figure 1 shows a grinding machine 10 having a grinding wheel 12 driven by a motor 14 and mounted on a wheelhead 16 for movement towards and away from a workpiece 18 along a linear track 20 under the control of the wheelfeed drive motor 22. The workpiece 18 is mounted on a carriage 70 itself slidable on a slideway 32 and driven thereby to position the workpiece relative to the wheel, via a drive 74. The workpiece is mounted between centres in a tailstock 24 and a headstock 26 (themselves mounted on the carriage 70). The headstock houses a motor (not shown) for rotating the workpiece 18 via a chuck 28. The workpiece shown is a crankshaft of an internal combustion engine and includes offset crankpins 30 (which are eccentric to the main crankshaft axis), and cylindrical bearing regions 31, which are to be ground to size, each bearing region

constituting a cylindrical workpiece region for grinding which should be concentric with the workpiece axis.

A computer 32 loaded with workpiece data and operating programmes (such as are to be described) controls the operation of the machine and inter alia moves the wheelhead 16 towards and away from the workpiece 18 as the workpiece rotates, so as to maintain contact between the wheel and the journal bearing region being ground. Some data can be entered via the keyboard 33. Data/results/process steps can be displayed on the screen 35.

A gauge, generally designated 34, is carried by the wheel head assembly for gauging the diameter of the regions being ground. This can be done while the workpiece is rotated slowly, and preferably without the grinding wheel in contact, after grinding. The gauge is shown in its parked, non-operating position in Figure 1. During gauging it is advanced so that the fingers of the gauge (described in more detail with reference to Figure 2) are first located on the opposite side of the workpiece from the wheel 12, so that they can be lowered and moved back towards the wheel so as to be located above and below the workpiece, and then moved towards the latter until they touch it at diametrically opposite regions for gauging.

The gauge was designed to allow the gauging of crankpins as they are ground, and Figure 2 shows how the fingers 36 and 38 can engage a journal bearing region 31. The dotted outlines 40, 42 show the extreme positions of the pin relative to the wheel 12 as the pin is rotated around the axis of the crankshaft, and describes a vertical path as seen by the wheel 12. Pneumatic drives 44, 46 and 48 produce relative movement between the gauge assembly and the wheelhead 16, between the gauge assembly and the workpiece, and between the two fingers 36 and 38.

A sensor 50 determines the spacing between the fingers 36, 38

and provides a spacing signal for the computer 32, from which the diameter of the workpiece region between the fingers can be computed. The sensor can also provide a signal indicative of the linear oscillatory movement of the gauge finger 38 caused by any eccentricity in the ground region, by locking the two fingers 36, 38 so as to just lightly clamp the workpiece therebetween, and rotating the latter slowly and observing any movement of 38, relative to sensor 50.

Figure 3 shows diagrammatically the grinding wheel 12, the wheelhead 16, the slide 20 and a different type of gauge from that shown in Figures 1 and 2. This engages a journal bearing workpiece region 31 by means of two fixed converging fingers 52, 54 with a sensor 55 for determining the distance between the converging fingers at which the fingers make contact with the workpiece. The computer 32 receives the gauging signals along line 56 and can compute therefrom the diameter of the workpiece region and delivers inter alia a position signal to the wheelhead drive via lines 58 + 59. Not shown are the signal paths from the computer 32 to the other drives for moving the gauge into and out of engagement and controlling the speed of rotation of the crankshaft. Although developed to measure crankpin diameters during grinding, this type of gauge can also be used to determine any eccentricity in the rotating workpiece region, by urging the gauge fingers 52, 54 into contact as shown and converting any in line movement of the gauge assembly 60, due to eccentricity, into an appropriate electrical signal using a transducer such as 57.

Wheel position signals from transducer encoder 41 are passed to the computer 32 via line 43.

As described in our copending UK Application 9702550.6 which describes a method of guiding crankpins to size using in process gauging, a technique is also described to obtain a high quality surface finish and highly accurate diameters of ground components. This technique may also be used when grinding

journal bearing regions. Thus during grinding, an initial fast wheelfeed may be used to roundout- journal bearing region 31, and the fast grinding feed stopped after a fixed feed amount independent of the gauge. At the end of the fast feed the gauge 34 is used by the machine control computer to sample the size of the region 31 and to check any eccentricity in magnitude and angular position as determined by the rotated position of the workpiece at which the eccentricity is noted. A prerequisite for the grinding cycle to proceed beyond this point is that this sample of size sensibly confirms that the gauge is on the region and functioning properly.

After computing the necessary control signal to compensate for any measured eccentricity the grinding feed restarts. A lower feed rate may be used.

In normal operation the feed will be stopped in response to signals derived from the wheel position and/or the in-process gauge 34 in a diameter measuring mode, and sampled by the machine control computer 32.

In a method, which involves in process gauging as the grinding feed proceeds towards a target size, near final size the instantaneous size of the region 31 being ground can be continuously sampled by the machine control computer.

If one or two or more consecutive samples of region 31 size, are found to be at or below the target size, the controlling computer immediately stops the grinding feed and initiates a feed dwell. This dwell, measured as N workpiece turns, permits the region being ground to achieve good geometric roundness and a stable size. This procedure gives an optimum response to fast grinding feeds commensurate with fast manufacturing times. During this feed dwell, typically two work revolutions, the controlling computer stores a number of consecutive samples of size measured at different angular positions relative to the gauge fingers so that it can calculate an average value of the

workpiece region diameter.

At the completion of this dwell, the average diameter value may be calculated, and this value used to calculate the feed distance to achieve the desired final size of the region. The controlling computer then initiates an incremental feed to final size. At the start of this incremental feed, the gauge, having completed its work, can be retracted, with the object of minimising manufacturing time. Because the feed to final size is not being controlled by gauge, it does not have to be slow but can be optimised to eliminate the build-up of machining vibrations and/or minimise machining time.

After a final "sparkout feed dwell", measured as n workpiece turns, the grinding wheel can be retracted, initially at a slow rate so as not to leave any grinding wheel breakaway mark, and then at a faster rate to minimise manufacturing time.

Alternatively, machining may be achieved without such in process gauging, simply by controlling the wheelfeed and gauging components off-line, and correcting for process induced eccentricity in accordance with the present invention and for wheel wear by appropriate adjustment as the grinding of a batch of workpieces progresses.

Figure 4 illustrates the steps of a method of grinding one component having a number of cylindrical surfaces which are to be ground concentric to the primary axis of the component. The same process is followed for each component to be ground.

Detailed programme steps required to set up and operate a grinding machine in different ways, in accordance with different aspects of the invention are now listed on the following pages.

The list of computer controlled operations which follow illustrate the steps which the machine controlling computer

must initiate the inputs it must respond to and the decisions it must make, under the control of programmes loaded into its memory, so as to adjust the wheelfeed control signals and other machine parameters and parts so as to set up the machine to thereafter grind a journal bearing region of a crankshaft, in accordance with different methods embodying the invention, as detailed.

A brief explanation of the process to which the steps relate is provided at the head of each listing.

Set-up routine/programmes

1. Routine for setting up a computer controlled grinding machine for grinding a workpiece having one region to be concentrically ground, and for subsequent grinding of similar workpieces

1. Load workpiece data into machine computer
2. Load wheelfeed programme for workpiece region
3. Enter target wheel advance for region
4. Mount workpiece
5. Rotate workpiece about primary axis for grinding
6. Align grinding wheel with region to be ground
7. Initiate wheelfeed and advance wheel to engage region
7 Grind workpiece and measure wheelhead advance
9. Stop wheelfeed when desired wheel advance achieved
10. Disengage wheel and workpiece
11. Apply gauge to ground region
12. Rotate workpiece slowly
13. Gauge ground diameter and store diameter measurements.
14. Identify any eccentricity and its rotational position
15. Adjust wheelfeed programme for eccentricity
16. Enter new target wheel advance
17. Grind workpiece using adjusted wheelfeed programme
18. Measure wheelhead advance
19. Stop wheelfeed when required advance achieved
20. Retract wheel
21. Stop workpiece rotation
22. Demount workpiece
23. More similar workpieces? - Yes or No
24. If Yes, go to 25, if No, go to 27
25. Mount new workpiece
26. Go to 16
27. END

2. Similar routine where workpiece is to be removed for gauging

1. Load workpiece data into machine computer
2. Load wheelfeed programme for workpiece region
3. Enter target wheel advance for region
4. Mount workpiece
5. Rotate workpiece about primary axis for grinding
6. Align grinding wheel with region to be ground
7. Initiate wheelfeed and advance wheel to engage region
8. Grind workpiece and measure wheelhead advance
9. Stop wheelfeed when desired wheel advance achieved
10. Disengage wheel and workpiece
11. Stop workpiece rotation
12. Demount workpiece and stress relieve off machine
13. Gauge workpiece diameter and note any eccentricity
14. Mark angular position of noted eccentricity
15. Remount workpiece with mark at a particular position
16. Enter eccentricity details into machine computer
17. Adjust wheelfeed programme for eccentricity
18. Rotate workpiece about primary axis
19. Grind workpiece using adjusted wheelfeed programme
20. Measure wheelhead advance
21. Stop wheelfeed when final advance achieved
22. Retract wheel
23. Stop workpiece rotation
24. Demount workpiece
25. More similar workpieces? - Yes or No
26. If Yes, go to 27. If No, go to 29
27. Mount new workpiece
28. Go to 17
29. END

3\. Set up routine for a computer controlled grinding machine for grinding a workpiece having two or more regions to be concentrically ground, and subsequent grinding of similar workpieces

1. Load workpiece data into machine computer
2. Load wheelfeed programme for workpiece regions
3. Enter target wheel advances for regions
4. Mount workpiece
5. Select a region near centre of workpiece to grind
6. Rotate workpiece about primary axis for grinding
7. Align grinding wheel with region to be ground
8. Initiate wheelfeed and advance wheel to engage region
9. Grind workpiece and measure wheelhead advance
10. Stop wheelfeed at desired wheel advance
11. Disengage wheel and workpiece
12. Engage diameter measuring gauge on ground region
13. Rotate workpiece slowly
14. Gauge ground diameter and store diameter measurements
15. Identify any eccentricity and its rotational position
16. Adjust regions wheelfeed programme for eccentricity
17. Identify positions of other regions to be ground
18. Compute adjusted wheelfeed programme for each other region
19. Rotate workpiece to grind
20. Advance wheel to engage workpiece region
21. Enter target wheel advance for region
22. Grind using adjusted wheelfeed programme for region
23. Measure wheel advance
24. Stop wheelfeed at required wheel advance
25. Retract wheel
26. More regions to be ground? - Yes or No
27. If Yes, go to 28. If No, go to 30
28. Select next region
29. Go to 19
30. Stop workpiece rotation
31. Demount workpiece

32. More workpieces? - Yes or No
33. If Yes, go to 34. If No, go to 36
34. Mount next workpiece
35. Go to 19
36. END

4. Alternative set-up routine for a computer controlled grinding machine for grinding a workpiece having two or more regions to be concentrically ground, and subsequent grinding of similar workpieces

1. Load workpiece data into machine computer
2. Load wheelfeed programme for workpiece regions
3. Enter target wheel advances for the regions
4. Mount workpiece
5. Select region to grind
6. Rotate workpiece about primary axis for grinding
7. Align grinding wheel with region to be ground
8. Initiate programme to deliver wheelfeed control signals
9. Advance wheel to engage region
10. Grind workpiece and measure wheel advance
11. Stop wheelfeed at desired wheel advance
12. Disengage wheel and workpiece
13. Engage diameter measuring gauge on ground region
14. Rotate workpiece slowly
15. Gauge ground diameter and store diameter measurements
16. Identify any eccentricity and its rotational position
17. Adjust region's wheelfeed programme for eccentricity
18. More regions to be ground? - Yes or No
19. If Yes, go to 5; If No, go to 20
20. Select region to regrind
21. Rotate workpiece about primary axis for grinding
22. Enter target wheel advance for region
23. Align grinding wheel with region to be ground
24. Initiate adjusted wheelfeed programme for region
25. Advance wheel to engage region
26. Grind region and measure wheel advance
27. Stop wheelfeed at desired wheel advance and retract
28. More regions to regrind? Yes or No
29. If Yes, go to 20; If No, go to 30
30. Stop workpiece rotation
31. Demount workpiece

32. More workpieces? - Yes or No
33. If Yes, go to 34. If No, go to 36
34. Mount next workpiece
35. Go to 20
36. END

5. Set-up routine for a computer controlled grinding machine for grinding of workpieces having two or more regions which are to be concentrically ground, in which the machine parameters are set up by repeatedly grinding a first workpiece or a series of workpieces until the gauged results from each grinding are within pre-set limits and for subsequent grinding of similar workpieces using the machine as set up

1. Load workpiece data in machine computer
2. Load wheelfeed programme for workpiece regions
3. Enter target wheel advances for the regions
4. Mount workpiece
5. Select region to grind
6. Rotate workpiece about primary axis for grinding
7. Align grinding wheel with region to be ground
8. Initiate programme to delivery wheelfeed for the region
9. Advance wheel to engage region
10. Grind workpiece and measure wheel advance
11. Stop wheelfeed at desired wheel advance
12. Disengage wheel and workpiece
13. Engage diameter measuring gauge on ground region
14. Rotate workpiece slowly
15. Gauge ground diameter and store diameter measurements
16. Identify and store eccentricity magnitude and position
17. Adjust region's wheelfeed programme for eccentricity
18. More regions to be ground? Yes or No
19. If Yes, go to 4; if No, go to 20
20. Advance wheel to engage workpiece region
21. Grind workpiece using adjusted wheelfeed for engaged region
22. Measure wheel advance
23. Stop wheelfeed when required advance achieved
24. Disengage wheel
25. Rotate workpiece slowly
26. Gauge diameter and store region's diameter value
27. Identify any eccentricity and its rotational position
28. Store magnitude and position of region's eccentricity

29. Compare with previously stored values for region
30. Compute differences between two sets of values
31. Compare size of differences with predetermined limits
32. Store comparison results for region
33. More regions to be ground? Yes or No
34. If Yes, go to 35; if No, go to 37
35. Align wheel with region to be ground
36. Go to 20
37. Read stored comparison results
38. If all results favourable, go to 39; if not, go to 20
39. Preserve final adjusted wheelfeed programme values
40. Demount workpiece
41. End of Set-up. Begin grinding? Yes or No
42. If Yes, go to 43; if No, go to 53
43. Mount workpiece
44. Align wheel with region to be ground

45 Advance and grind using final adjusted wheelfeed programme values

46. Measure wheel advance
47. Stop wheelfeed at desired advance
48. Retract wheel
49. Stop workpiece rotation
50. Demount workpiece
51. More workpieces? Yes or No
52. If Yes, go to 43; if No, go to 53
53. Enter STANDBY MODE

6. Set-up routine for a computer controlled grinding machine for grinding workpieces having two or more regions to be concentrically ground in which the wheelfeed and other parameters required for grinding are computed as the mean of a purality of values derived by a sequence of measurements on a plurality of test workpieces, and subsequent grinding of similar workpieces using the machine as set up

1. Load workpiece data in machine computer
2. Load wheelfeed programme for workpiece regions
3. Enter target wheel advances for the regions
4. Mount workpiece and reset counter to zero
5. Select region to grind
6. Rotate workpiece about primary axis for grinding
7. Align grinding wheel with region to be ground
8. Initiate programme to delivery wheelfeed for the region
9. Advance wheel to engage region
10. Grind workpiece and measure wheel advance
11. Stop wheelfeed at desired wheel advance
12. Disengage wheel and workpiece
13. Engage diameter measuring gauge on ground region
14. Rotate workpiece slowly
15. Gauge ground diameter and store diameter measurements
16. Identify and store eccentricity magnitude and position
17. More regions to be ground? Yes or No
18. If Yes, go to 5; if No, go to 19
19. Increment workpiece counter by one
20. Demount workpiece
21. More workpieces to be checked? Yes or No
22. If Yes, go to 4; if No, go to 23
23. Compute arithmetic mean of adjusted wheelfeed control signals for each region using counter value
24. Store mean wheelfeed signals for each region in place of originally loaded wheelfeed programme
25. Store final wheel advances for the regions in place of data entered in step 3

26. End of set up. Begin grinding? Yes or No
27. If Yes, go to 28; if No, go to 43
28. Mount workpiece
29. Select region to grind
30. Rotate workpiece about primary axis for grinding
31. Align grinding wheel with region to be ground
32. Advance wheel to engage region
33. Control wheelfeed using mean wheelfeed signals for region
34. Grind workpiece and measure wheel advance
35. Stop wheelfeed at desired wheel advance
36. Disengage wheel and workpiece
37. More regions to grind? Yes or No
38. If Yes, go to 29; if No, go to 39
39. Demount workpiece
40. More workpieces? Yes or No
41. If Yes, go to 28; if No go to 42
42. END
43. Enter STANDBY MODE

Claims

A method of setting up a computer controlled grinding machine for concentrically grinding cylindrical workpiece regions, comprising the steps of loading a programme containing data about the workpiece, loading a program containing wheelfeed instructions, running the wheelfeed instruction programme so as to grind at least one such workpiece region to final form, measuring any unwanted eccentricity introduced by the grinding process together with the angular position(s) thereof in the said at least one workpiece region, and adjusting the wheelfeed programme instructions or control signals so that during subsequent grinding of the said region (or of similar regions of similar workpieces), the wheelfeed is controlled so as to compensate for said measured unwanted eccentricity.

2. The method of Claim 1 wherein the measuring of the workpiece region occurs after it has been stress relieved.

3. The method of Claim 2 wherein the workpiece is stress relieved by disengaging the grinding wheel.

4. The method of Claim 1, 2 or 3 as applied to an elongate workpiece containing a plurality of such regions to be ground at spaced apart positions axially therealong and which is supported at opposite ends, wherein the setting up process measurements are performed on a concentric cylindrical region approximately midway along the axial length of the workpiece, and proportionately reduced corrections are applied to the wheelfeed programme instructions or control signals to be used for similar regions to be ground and which are displaced from the mid position towards one or the other of the supported ends of the workpiece.

5. A method of setting up a computer controlled grinding

machine to grind elongate workpieces supported at opposite ends for grinding in which unwanted eccentricity introduced by the grinding process forces can vary in extent along the axial length thereof (as measured with reference to its supported ends), such that regions towards the centre of the workpiece require a greater degree of eccentricity compensation during grinding as opposed to those adjacent the ends thereof, the method comprising the steps of cylindrically grinding all of the cylindrical surfaces of a workpiece which are to be concentric with the primary workpiece axis without introducing any compensation for unwanted eccentricity introduced by the grinding process forces, thereafter making measurements on the workpiece to determine any unwanted eccentricity and the angular position thereof about the primary workpiece axis of rotation for each of the ground regions, and separately adjusting each of the wheelfeed programme instructions or control signals to be used to control the wheelfeed during the subsequent grinding of the or another similar such workpiece, at each of the corresponding said regions thereof, so as to compensate individually for any process-induced eccentricity in each said region.

6. A method as claimed in any of Claims 1 to 5 wherein after a setting up process has been performed and the original workpiece has been reground using the corrected wheelfeed programme instructions or control signals, a further gauging of the reground workpiece is performed, and second order corrections are made to the wheelfeed programme instructions or control signals, before grinding further workpieces.

7. A method as claimed in Claim 6 wherein measurements are made subsequent to each further workpiece grinding to determine whether the corrections made from earlier measurements sufficiently compensate for any unwanted process induced eccentricity, and further corrections are made to the wheelfeed programme instructions or control signals as required.

8. A method as claimed in Claim 7 wherein the process is repeated until the measurements made on a test workpiece indicate that the unwanted eccentricity of each ground region is within desired limits.

9. A method as claimed in any of claims 1 to 8 wherein after the wheelfeed programme instructions or control signals have been modified, the grinding machine wheelfeed is thereafter controlled by means of the modified instructions or control signals, to grind workpieces similar to that used during the setting up.

10. A method of setting up a computer controlled grinding machine as claimed in Claim 1 or Claim 5 in which instead of producing only one workpiece on which measurements are made during the setting up, at each stage a plurality of workpieces are ground which together form a sample, and eccentricity measurements are made on all the workpieces in each sample, thereby to determine the extent of any unwanted eccentricity both in terms of angular position and radial extent for each region of each workpiece in each sample, and the mean unwanted eccentricity and mean angular position of such eccentricity is determined for each sample, for use as the basis for the correction to the wheelfeed programme instructions or control signals.

11. A method as claimed in Claim 10 wherein the process for determining what is to be the final set of programme instructions or control signals for the wheelfeed, is terminated if the measurements of unwanted eccentricity in all of the workpieces in a sample fall within desired limits.

12. A method as claimed in Claim 10 wherein the process for determining what is to be the final set of programme instructions or control signals for the wheelfeed, is terminated if the mean of all the measurements of unwanted eccentricity fall within desired limits.

13. A method of grinding concentric cylindrical regions of similar workpieces comprising the steps of setting up modified wheelfeed programme instructions or control signals by a method as claimed in any of the preceding claims and thereafter grinding cylindrical surfaces of workpieces similar to that used in the setting up process, using the modified wheelfeed programme instructions or control signals derived from the setting up procedure, to control the wheelfeed drive during each grinding.

14. A grinding method as claimed in Claim 13 which uses a high speed CBN grinding wheel, thereby eliminating the rough machining step required before a fine grinding step to produce a bearing surface, thereby allowing a two stage grinding and polishing process to produce a finished product, instead of a three stage process.

15. A method of grinding concentric cylindrical surfaces of a crankshaft using at a smaller scale a software controlled crankpin following facility incorporated into a computer controlled grinding machine which permits a grinding wheel to follow the relatively excessive eccentric movement of a crankpin during grinding as the crankshaft rotates, to compensate for unwanted eccentricity introduced into the cylindrically ground surfaces of the workpiece as a consequence of grinding process forces exerted as such surfaces are ground, and which tends to appear after the workpiece is stress relieved.

16. A method of operating a computer controlled grinding machine so as to eccentrically grind a region of a workpiece which is to have a cylindrical surface concentric relative to the workpiece primary axis after grinding, rather than concentrically cylindrically grinding the said region, the degree of eccentricity being such that when the cylindrically ground workpiece is stress relieved after grinding, the region

will be concentric relative to the primary axis of the workpiece.

17. A computer controlled grinding machine for performing methods of grinding as claimed in any of Claims 13 to 16 comprising a grinding wheel, drive means for rotating the wheel, wheelfeed drive means for advancing and withdrawing the grinding wheel towards and away from a workpiece region in a precise manner, computer means for controlling the wheelfeed drive means, which computer means includes memory means for storing programmable wheelfeed instructions whereby the position of the wheel at each instant during a grinding process can be controlled, programme means loaded into the computer to control advance and withdrawal and position of the grinding wheel, and memory means for storing correction signals for adjusting the original wheelfeed instructions or control signals derived therefrom during the grinding of said regions, or storing corrected wheelfeed programme instructions or corrected signals, which correcting or corrected instructions, or signals are obtained from a setting up process as claimed in any of Claims 1 to 12.

18. A computer controlled grinding machine as claimed in Claim 17 when programmed to operated a grinding process which will reduce unwanted eccentricity introduced by grinding process forces into what should be a concentric cylindrical workpiece region, by grinding each such region so as to be complementarily eccentric to any eccentricity which would be introduced by the grinding process forces.

19. A computer controlled grinding machine as claimed in Claim 18 in which the grinding wheel is to be moved axially relative to the workpiece (or the workpiece is to be moved axially relative to grinding wheel) to allow different regions to be ground, and wherein the computer means includes additional programme instructions to control the movement of the wheel or the workpiece to effect said relative positioning between

grinding.

20. A computer controlled grinding machine when programmed as claimed in Claim 19 in which the wheelfeed drive includes two modes, a first mode for normal advance and withdrawal, and a second mode in which very small but very precise adjustments are made to the instantaneous wheel position so that during grinding, with the grinding wheel in contact with the workpiece and surface grinding being performed, the grinding wheel can be urged backwards and forwards by very small amounts in synchronism and appropriate phase with the rotation of the workpiece, using corrected wheelfeed programme instructions or control signals obtained by means of a setting up method as claimed in any of claims 1 to 12, so as to compensate for any eccentricity which would otherwise arise in the grinding of the workpiece region due to forces arising during the grinding process.

21. Workpieces when made in accordance with any of the methods of claims 13 to 16 or using a grinding machine as claimed in any of Claims 17 to 21.

22. A computer programme for controlling a computer controlled grinding machine to set up the wheelfeed instructions to control grinding of workpieces having a single region to be ground comprising the following steps:

1. Load workpiece data into machine computer
2. Load wheelfeed programme for workpiece region
3. Enter target wheel advance for region
4. Mount workpiece
5. Rotate workpiece about primary axis for grinding
6. Align grinding wheel with region to be ground
7. Initiate wheelfeed and advance wheel to engage region
7 Grind workpiece and measure wheelhead advance
9. Stop wheelfeed when desired wheel advance achieved
10. Disengage wheel and workpiece

11. Apply gauge to ground region
12. Rotate workpiece slowly
13. Gauge ground diameter and store diameter measurements.
14. Identify any eccentricity and its rotational position
15. Adjust wheelfeed programme for eccentricity
16. Enter new target wheel advance
17. Grind workpiece using adjusted wheelfeed programme
18. Measure wheelhead advance
19. Stop wheelfeed when required advance achieved
20. Retract wheel
21. Stop workpiece rotation
22. Demount workpiece
23. More similar workpieces? - Yes or No
24. If Yes, go to 25, if No, go to 27
25. Mount new workpiece
26. Go to 16
27. END

23. A computer programme for controlling a computer controlled grinding machine to set up the wheelfeed instructions to control grinding of workpieces having a single region to be ground comprising the following steps:

1. Load workpiece data into machine computer
2. Load wheelfeed programme for workpiece region
3. Enter target wheel advance for region
4. Mount workpiece
5. Rotate workpiece about primary axis for grinding
6. Align grinding wheel with region to be ground
7. Initiate wheelfeed and advance wheel to engage region
8. Grind workpiece and measure wheelhead advance
9. Stop wheelfeed when desired wheel advance achieved
10. Disengage wheel and workpiece
11. Stop workpiece rotation
12. Demount workpiece and stress relieve off machine
13. Gauge workpiece diameter and note any eccentricity
14. Mark angular position of noted eccentricity

15. Remount workpiece with mark at a particular position
16. Enter eccentricity details into machine computer
17. Adjust wheelfeed programme for eccentricity
18. Rotate workpiece about primary axis
19. Grind workpiece using adjusted wheelfeed programme
20. Measure wheelhead advance
21. Stop wheelfeed when final advance achieved
22. Retract wheel
23. Stop workpiece rotation
24. Demount workpiece
25. More similar workpieces? - Yes or No
26. If Yes, go to 27. If No, go to 29
27. Mount new workpiece
28. Go to 17
29. END

24. A computer programme for controlling a computer controlled grinding machine to set up the wheelfeed instructions to control grinding of workpieces have plural regions to be ground comprising the following steps:

1. Load workpiece data into machine computer
2. Load wheelfeed programme for workpiece regions
3. Enter target wheel advances for regions
4. Mount workpiece
5. Select a region near centre of workpiece to grind
6. Rotate workpiece about primary axis for grinding
7. Align grinding wheel with region to be ground
8. Initiate wheelfeed and advance wheel to engage region
9. Grind workpiece and measure wheelhead advance
10. Stop wheelfeed at desired wheel advance
11. Disengage wheel and workpiece
12. Engage diameter measuring gauge on ground region
13. Rotate workpiece slowly
14. Gauge ground diameter and store diameter measurements
15. Identify any eccentricity and its rotational position
16. Adjust regions wheelfeed programme for eccentricity

17. Identify positions of other regions to be ground
18. Compute adjusted wheelfeed programme for each other region
19. Rotate workpiece to grind
20. Advance wheel to engage workpiece region
21. Enter target wheel advance for region
22. Grind using adjusted wheelfeed programme for region
23. Measure wheel advance
24. Stop wheelfeed at required wheel advance
25. Retract wheel
26. More regions to be ground? - Yes or No
27. If Yes, go to 28. If No, go to 30
28. Select next region
29. Go to 19
30. Stop workpiece rotation
31. Demount workpiece
32. More workpieces? - Yes or No
33. If Yes, go to 34. If No, go to 36
34. Mount next workpiece
35. Go to 19
36. END

25. A computer programme for controlling a computer controlled grinding machine to set up the wheelfeed instructions to control grinding of workpieces having plural regions to be ground comprising the following steps:

1. Load workpiece data into machine computer
2. Load wheelfeed programme for workpiece regions
3. Enter target wheel advances for the regions
4. Mount workpiece
5. Select region to grind
6. Rotate workpiece about primary axis for grinding
7. Align grinding wheel with region to be ground
8. Initiate programme to deliver wheelfeed control signals
9. Advance wheel to engage region
10. Grind workpiece and measure wheel advance
11. Stop wheelfeed at desired wheel advance

12. Disengage wheel and workpiece
13. Engage diameter measuring gauge on ground region
14. Rotate workpiece slowly
15. Gauge ground diameter and store diameter measurements
16. Identify any eccentricity and its rotational position
17. Adjust region's wheelfeed programme for eccentricity
18. More regions to be ground? - Yes or No
19. If Yes, go to 5; If No, go to 20
20. Select region to regrind
21. Rotate workpiece about primary axis for grinding
22. Enter target wheel advance for region
23. Align grinding wheel with region to be ground
24. Initiate adjusted wheelfeed programme for region
25. Advance wheel to engage region
26. Grind region and measure wheel advance
27. Stop wheelfeed at desired wheel advance and retract
28. More regions to regrind? Yes or No
29. If Yes, go to 20; If No, go to 30
30. Stop workpiece rotation
31. Demount workpiece
32. More workpieces? - Yes or No
33. If Yes, go to 34. If No, go to 36
34. Mount next workpiece
35. Go to 20
36. END

26. A computer programme for controlling a computer controlled grinding machine to set up the wheelfeed instructions to control grinding of workpieces having plural regions to be ground comprising the following steps:

1. Load workpiece data in machine computer
2. Load wheelfeed programme for workpiece regions
3. Enter target wheel advances for the regions
4. Mount workpiece
5. Select region to grind
6. Rotate workpiece about primary axis for grinding

7. Align grinding wheel with region to be ground
8. Initiate programme to delivery wheelfeed for the region
9. Advance wheel to engage region
10. Grind workpiece and measure wheel advance
11. Stop wheelfeed at desired wheel advance
12. Disengage wheel and workpiece
13. Engage diameter measuring gauge on ground region
14. Rotate workpiece slowly
15. Gauge ground diameter and store diameter measurements
16. Identify and store eccentricity magnitude and position
17. Adjust region's wheelfeed programme for eccentricity
18. More regions to be ground? Yes or No
19. If Yes, go to 4; if No, go to 20
20. Advance wheel to engage workpiece region
21. Grind workpiece using adjusted wheelfeed for engaged region
22. Measure wheel advance
23. Stop wheelfeed when required advance achieved
24. Disengage wheel
25. Rotate workpiece slowly
26. Gauge diameter and store region's diameter value
27. Identify any eccentricity and its rotational position
28. Store magnitude and position of region's eccentricity
29. Compare with previously stored values for region
30. Compute differences between two sets of values
31. Compare size of differences with predetermined limits
32. Store comparison results for region
33. More regions to be ground? Yes or No
34. If Yes, go to 35; if No, go to 37
35. Align wheel with region to be ground
36. Go to 20
37. Read stored comparison results
38. If all results favourable, go to 39; if not, go to 20
39. Preserve final adjusted wheelfeed programme values
40. Demount workpiece
41. End of Set-up. Begin grinding? Yes or No
42. If Yes, go to 43, if No, go to 53
43. Mount workpiece

44. Align wheel with region to be ground
45. Advance to grind using final adjusted wheelfeed programme values
46. Meaure wheel advance
47. Stop wheelfeed at desired advance
48. Retract wheel
49. Stop workpiece rotation
50. Demount workpiece
51. More workpieces? Yes or No
52. If Yes, go to 43; if No, go to 53
53. Enter Standby Mode

27. A computer programme for controlling a computer controlled thereafter grinding machine to set up the wheelfeed instructions to control the grinding of workpieces having plural regions to be ground comprising the following steps:

1. Load workpiece data in machine computer
2. Load wheelfeed programme for workpiece regions
3. Enter target wheel advances for the regions
4. Mount workpiece and reset workpiece counter to zero
5. Select region to grind
6. Rotate workpiece about primary axis for grinding
7. Align grinding wheel with region to be ground
8. Initiate programme to delivery wheelfeed for the region
9. Advance wheel to engage region
10. Grind workpiece and measure wheel advance
11. Stop wheelfeed at desired wheel advance
12. Disengage wheel and workpiece
13. Engage diameter measuring gauge on ground region
14. Rotate workpiece slowly
15. Gauge ground diameter and store diameter measurements
16. Identify and store eccentricity magnitude and position
17. More regions to be ground? Yes or No
18. If Yes, go to 5; if No, go to 19
19. Increment workpiece counter by one
20. Demount workpiece

21. More workpieces to be checked? Yes or No
22. If Yes, go to 4; if No, go to 23
23. Compute arithmetic mean of adjusted wheelfeed control signals for each region using counter value
24. Store mean wheelfeed signals for each region in place of originally loaded wheelfeed programme
25. Store final wheel advances for the regions in place of data entered in step 3
26. End of set up. Begin grinding? Yes or No
27. If Yes, go to 28; if No, go to 43
28. Mount workpiece
29. Select region to grind
30. Rotate workpiece about primary axis for grinding
31. Align grinding wheel with region to be ground
32. Advance wheel to engage region
33. Control wheelfeed using mean wheelfeed signals for region
34. Grind workpiece and measure wheel advance
35. Stop wheelfeed at desired wheel advance
36. Disengage wheel and workpiece
37. More regions to grind? Yes or No
38. If Yes, go to 29; if No, go to 39
39. Demount workpiece
40. More workpieces? Yes or No
41. If Yes, go to 28; if No go to 42
42. END
43. Enter STANDBY MODE

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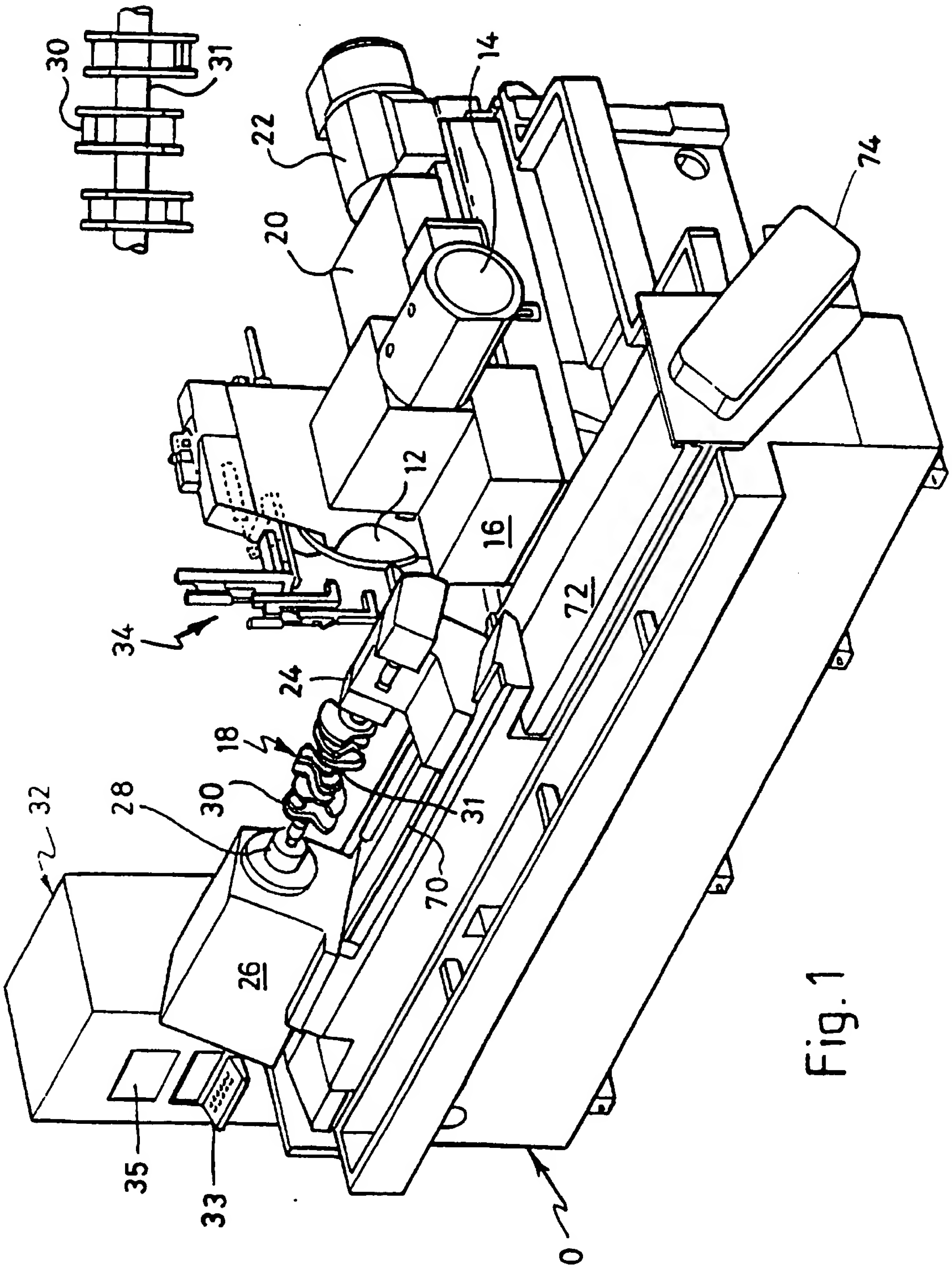

Fig. 1

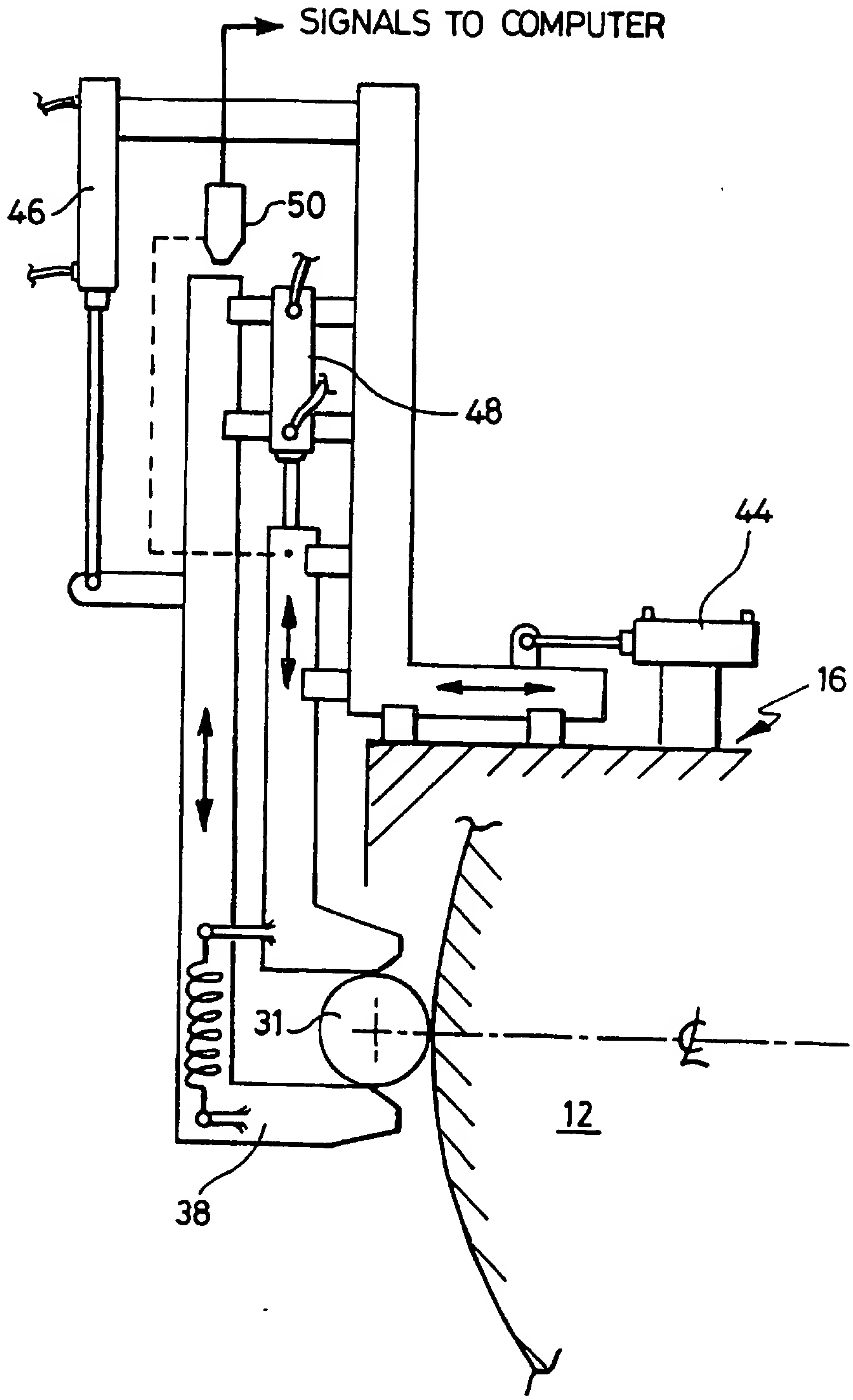

Fig. 2

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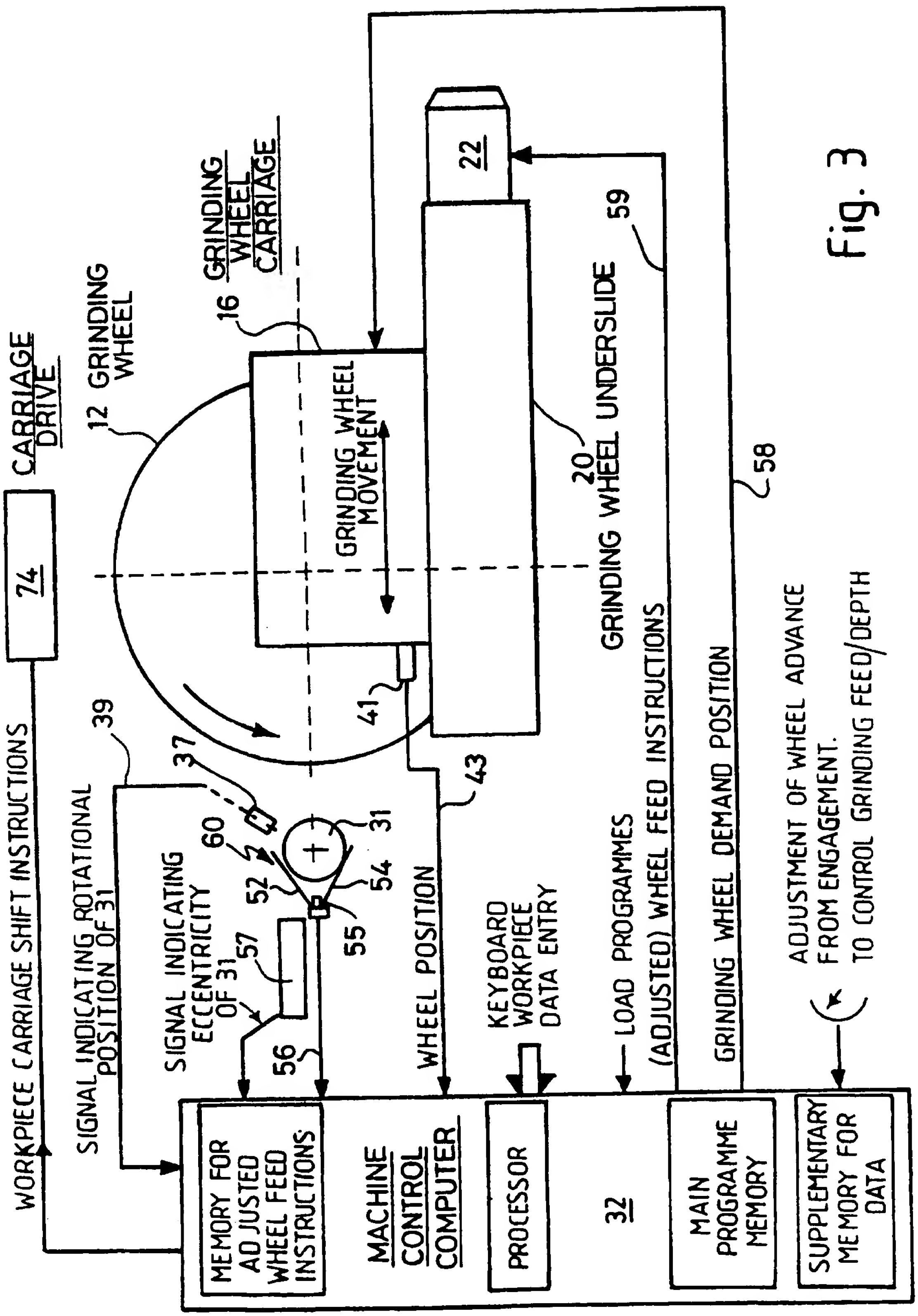
CARRIAGE DRIVE
74
12 GRINDING WHEEL
16
GRINDING WHEEL CARRIAGE
GRINDING WHEEL MOVEMENT
22
59
20
GRINDING WHEEL UNDERSLIDE
58
41
43
39
37
60
31
52
54
55
57
56
WORKPIECE CARRIAGE SHIFT INSTRUCTIONS
SIGNAL INDICATING ROTATIONAL POSITION OF 31
SIGNAL INDICATING ECCENTRICITY OF 31
WHEEL POSITION
KEYBOARD WORKPIECE DATA ENTRY
LOAD PROGRAMMES
(ADJUSTED) WHEEL FEED INSTRUCTIONS
GRINDING WHEEL DEMAND POSITION
ADJUSTMENT OF WHEEL ADVANCE FROM ENGAGEMENT. TO CONTROL GRINDING FEED/DEPTH
MEMORY FOR ADJUSTED WHEEL FEED INSTRUCTIONS
MACHINE CONTROL COMPUTER
PROCESSOR
32
MAIN PROGRAMME MEMORY
SUPPLEMENTARY MEMORY FOR DATA

Fig. 3

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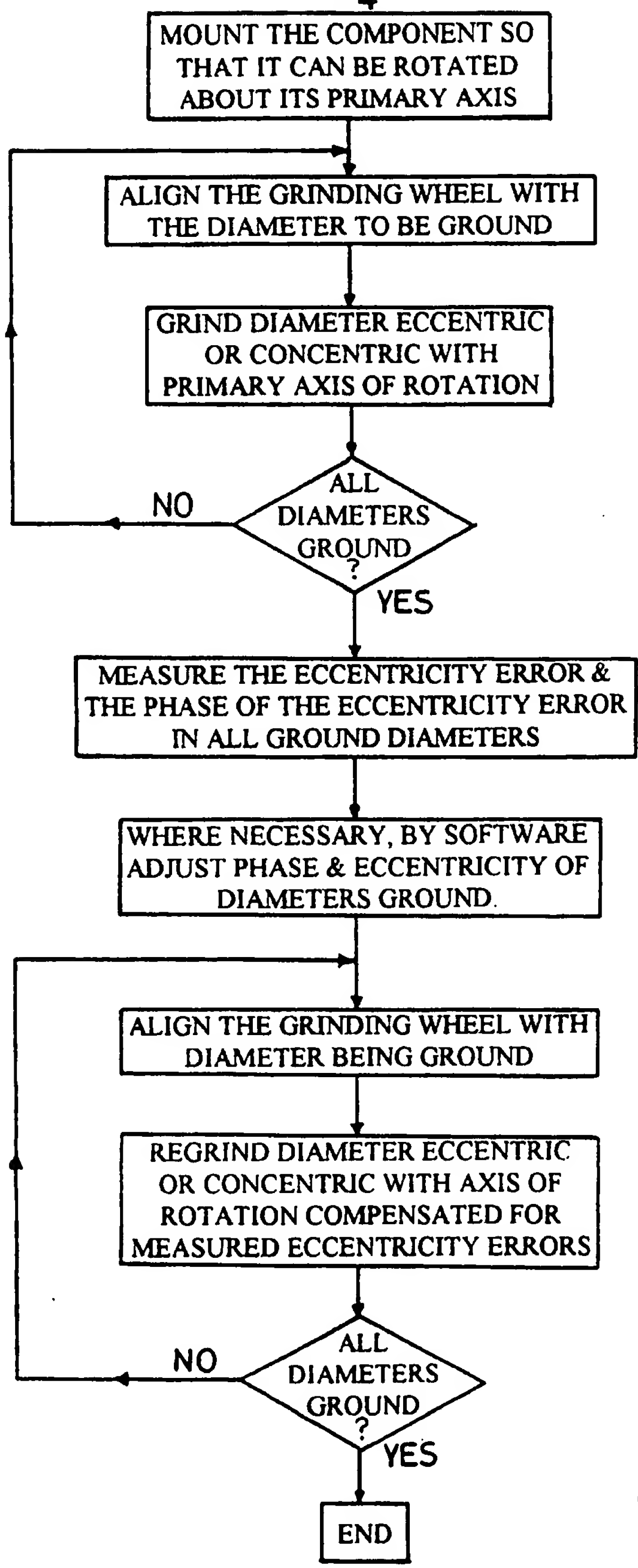
MOUNT THE COMPONENT SO THAT IT CAN BE ROTATED ABOUT ITS PRIMARY AXIS
ALIGN THE GRINDING WHEEL WITH THE DIAMETER TO BE GROUND
GRIND DIAMETER ECCENTRIC OR CONCENTRIC WITH PRIMARY AXIS OF ROTATION
ALL DIAMETERS GROUND ?
NO
YES
MEASURE THE ECCENTRICITY ERROR & THE PHASE OF THE ECCENTRICITY ERROR IN ALL GROUND DIAMETERS
WHERE NECESSARY, BY SOFTWARE ADJUST PHASE & ECCENTRICITY OF DIAMETERS GROUND.
ALIGN THE GRINDING WHEEL WITH DIAMETER BEING GROUND
REGRIND DIAMETER ECCENTRIC OR CONCENTRIC WITH AXIS OF ROTATION COMPENSATED FOR MEASURED ECCENTRICITY ERRORS
ALL DIAMETERS GROUND ?
NO
YES
END

Fig. 4

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 97/01110

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 G05B19/416

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 G05B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	DE 29 18 249 A (GOETZE AG) 6 November 1980 see page 4, paragraph 3 - page 7, paragraph 1; claim 1; figure 1	1,13, 17-19,21
Y		2,3,6,7, 9,15
A		5,8,14, 20-27
Y	EP 0 282 776 A (GEHRING GMBH MASCHINENFABRIK GMBH & CO. KG) 21 September 1988 see column 3, line 30 - column 5, line 1; figure A	2,3,6,7, 9,15

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

1

Date of the actual completion of the international search	Date of mailing of the international search report
11 August 1997	08.09.97

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Nettesheim, J

INTERNATIONAL SEARCH REPORT

Inten nal Application No
PCT/GB 97/01110

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	PATENT ABSTRACTS OF JAPAN vol. 013, no. 406 (P-930), 8 September 1989 & JP 01 147608 A (TOSHIBA MACH CO LTD), 9 June 1989, see abstract	1,4
A	US 5 419 222 A (BIEG LOTHAR F.) 30 May 1995 see claims 15,16 see column 10, line 22 - column 10, line 38	1,7,8, 13,14
A	EP 0 276 802 A (FORTUNA WERKE MASCHINENFABRIK AG.) 3 August 1988 see abstract; claim 1	1,10, 22-27

1 .

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/GB 97/01110

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
DE 2918249 A	06-11-80	GB 2051410 A,B	14-01-81
		JP 55150901 A	25-11-80
		US 4366543 A	28-12-82
EP 0282776 A	21-09-88	DE 3707326 A	15-09-88
		DE 3864706 A	17-10-91
		US 4831787 A	23-05-89
US 5419222 A	30-05-95	NONE	
EP 0276802 A	03-08-88	DE 3702594 A	11-08-88
		DE 3871162 A	25-06-92
		JP 6098568 B	07-12-94
		JP 63200957 A	19-08-88
		US 4885874 A	12-12-89